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(54) Title: HYDRAULIC STRAIN SENSOR		
(57) Abstract		
<p>A hydraulic strain sensor (16) for use with a downhole tool on a slickline, wireline, coiled tubing or drill string pipe type of conveyance device includes a housing having two chambers (38, 40) with a pressure differential between the two chambers. A mandrel (30), piston (34) and cylinder (26) is disposed in the housing, such mandrel being adapted for coupling to the tool so that the weight of the tool is supported by the pressure differential between the two chambers. A pressure-responsive sensor (54) in communication with one of the sealed chambers is provided to sense pressure changes in the chamber as the tool is accelerated or decelerated downhole along a borehole or wellbore and to generate signals representative of the pressure changes occurring in the chambers.</p>		

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HYDRAULIC STRAIN SENSOR**BACKGROUND OF THE INVENTION****1. Technical Field**

The invention relates generally to electrical downhole tools which are employed for various downhole oil-field applications, e.g., firing shaped charges through a casing and 5 setting a packer in a wellbore. More particularly, the invention relates to a pressure-actuated downhole tool and a method and an apparatus for generating pressure signals which may be interpreted as command signals for actuating the downhole tool.

2. Background Art

10 Electrical downhole tools which are used to perform one or more operations in a wellbore may receive power and command signals through conductive logging cables which run from the surface to the downhole tools. Alternatively, the downhole tool may be powered by batteries, and commands may be preprogrammed into the tool and executed in a predetermined order over a fixed time interval, or command signals may be sent to the tool 15 by manipulating the pressure exerted on the tool. The downhole pressure exerted on the tool is recorded using a pressure gage, and downhole electronics and software interpret the pressure signals from the pressure gage as executable commands. Typically, the downhole pressure exerted on the tool is manipulated by surface wellhead controls or by moving the tool over set vertical distances and at specified speeds in a column of fluid. However, 20 generating pressure signals using these typical approaches can be difficult, take excessively long periods of time to produce, or require too much or unavailable equipment. Thus, it would be desirable to have a means of quickly and efficiently generating pressure signals.

SUMMARY OF THE INVENTION

25 In general, in one aspect, a hydraulic strain sensor for use with a downhole tool comprises a housing having two chambers with a pressure differential between the two chambers. A mandrel disposed in the housing is adapted to be coupled to the tool such that the weight of the tool is supported by the pressure differential between the two chambers. A pressure-responsive member in communication with one of the chambers is arranged to

sense pressure changes in the one of the chambers as the tool is accelerated or decelerated and to generate signals representative of the pressure changes.

Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

5

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of a downhole assembly for use in performing a downhole operation in a wellbore.

FIG. 2 is a detailed view of the hydraulic strain sensor shown in FIG. 1.

10

DETAILED DESCRIPTION

Referring to the drawings wherein like characters are used for like parts throughout the several views, FIG. 1 depicts a downhole assembly 10 which is suspended in a wellbore 12 on the end of a conveyance device 14. The conveyance device 14 may be a slickline, 15 wireline, coiled tubing, or drill pipe. Although running the downhole assembly into the wellbore on a slickline or wireline is considerably faster and more economical than running on a coiled tubing or drill pipe. The downhole assembly 10 includes a hydraulic strain sensor 16 and a downhole tool 18 which may be operated to perform one or more downhole operations in response to pressure signals generated by the hydraulic strain sensor 16. For 20 example, the downhole tool 18 may be a perforating gun which may be operated to fire shaped charges through a casing 19 in the wellbore 12.

The hydraulic strain sensor 16 includes a sealed chamber (not shown) which experiences pressure changes when the downhole tool 18 is accelerated or decelerated and a pressure-responsive sensor, e.g., a pressure transducer (not shown), which detects the 25 pressure changes and converts them to electrical signals. The hydraulic strain sensor 16 communicates with the downhole tool 18 through an electronics cartridge 20. The electronics cartridge 20 includes electronic circuitry, e.g., microprocessors (not shown), which interprets the electrical signals generated by the pressure transducer as commands for operating the downhole tool 18. The electronics cartridge 20 may also include an electrical 30 power source, e.g., a battery pack (not shown), which supplies power to the electrical components in the downhole assembly 10. Power may also be supplied to the downhole assembly 10 from the surface, e.g., through a wireline, or from a downhole autonomous

power source.

Referring to FIG. 2, the hydraulic strain sensor 16 comprises a hydraulic power section 22 and a sensor section 24. The hydraulic power section 22 includes a cylinder 26. A fishing neck 28 is mounted at the upper end of the cylinder 26 and adapted to be coupled 5 to the conveyance device 14 (shown in FIG. 1) so that the hydraulic strain sensor 16 can be lowered into and retrieved from the wellbore on the conveyance device. With the fishing neck 28 coupled to the conveyance device 14, the hydraulic strain sensor 16 and other attached components can be accelerated or decelerated by jerking the conveyance device. The fishing neck 28 may also be coupled to other tools. For example, if the conveyance 10 device 14 is inadvertently disconnected from the fishing neck 28 so that the hydraulic strain sensor 16 drops to the bottom of the wellbore, a fishing tool, e.g., an overshot, may be lowered into the wellbore to engage the fishing neck 28 and retrieve the hydraulic strain sensor 16. The fishing neck 28 may be provided with magnetic markers (not shown) which allow it to be easily located downhole.

15 A mandrel 30 is disposed in and axially movable within a bore 32 in the cylinder 26. The mandrel 30 has a piston portion 34 and a shaft portion 36. An upper chamber 38 is defined above the piston portion 34, and a lower chamber 40 is defined below the piston portion 34 and around the shaft portion 36. The upper chamber 38 is exposed to the pressure outside the cylinder 26 through a port 42 in the cylinder 26. A sliding seal 44 between the 20 piston portion 34 and the cylinder 26 isolates the upper chamber 38 from the lower chamber 40, and a sliding seal 46 between the shaft portion 34 and the cylinder 26 isolates the lower chamber 40 from the exterior of the cylinder 26. The sliding seal 44 is retained on the piston portion 34 by a seal retaining plug 48, and the sliding seal 46 is secured to a lower end of the cylinder 26 by a seal retaining ring 50.

25 The sensor section 24 comprises a first sleeve 52 which encloses and supports a pressure transducer 54 and a second sleeve 56 which includes an electrical connector 58. The first sleeve 52 is attached to the lower end of a connecting body 62 with a portion of the pressure transducer 54 protruding into a bore 64 in the connecting body 62. An end 66 of the shaft portion 36 extends out of the cylinder 26 into the bore 64 in the connecting body 30 62. The end 66 of the shaft portion 26 is secured to the connecting body 62 so as to allow the connecting body 62 to move with the mandrel 30. Static seals, e.g., o-ring seals 76 and 78, are arranged between the connecting body 62 and the shaft portion 36 and pressure

transducer 54 to contain fluid within the bore 64.

The second sleeve 56 is mounted on the first sleeve 52 and includes slots 80 which are adapted to ride on projecting members 82 on the first sleeve 52. When the slots 80 ride on the projecting members 82, the hydraulic strain sensor 16 moves relative to the downhole 5 tool 18 (shown in FIG. 1). A spring 82 connects and normally biases an upper end 84 of the second sleeve 56 to an outer shoulder 86 on the first sleeve 52. The electrical connector 58 on the second sleeve 52 is connected to the pressure transducer 54 by electrical wires 88. When the hydraulic strain sensor 16 is coupled to the electronics cartridge 20 (shown in FIG. 10 1), the electrical connector 58 forms a power and communications interface between the pressure transducer 54 and the electronic circuitry and electrical power source in the electronics cartridge.

The shaft portion 36 has a fluid channel 90 which is in communication with the bore 64 in the connecting body 62. The fluid channel 90 opens to a bore 92 in the piston portion 34, and the bore 92 in turn communicates with the lower chamber 40 through ports 94 in the 15 piston portion 34. The bore 92 and ports 94 in the piston portion 34, the fluid channel 90 in the shaft portion 36, and the bore 64 in the connecting body 62 define a pressure path from the lower chamber 40 to the pressure transducer 54. The lower chamber 40 and the pressure path are filled with a pressure-transmitting medium, e.g., oil or other incompressible fluid, through fill ports 96 and 98 in the seal retaining plug 48 and the connecting body 62, 20 respectively. By using both fill ports 96 and 98 to fill the lower chamber 40 and the pressure path, the volume of air trapped in the lower chamber and the pressure path can be minimized. Plugs 100 and 102 are provided in the fill ports 96 and 98 to contain fluid in the pressure path and the lower chamber 40.

When the hydraulic strain sensor 16 is coupled to the downhole tool 18, as illustrated 25 in FIG. 1, the net force, F_{net} , resulting from the pressure differential across the piston portion 34 supports the weight of the downhole tool 18. The net force resulting from the pressure differential across the piston portion 34 can be expressed as:

$$F_{net} = (P_{lc} - P_{uc}) \cdot A_{lc} \quad (1)$$

where P_{lc} is the pressure in the lower chamber 40, P_{uc} is the pressure in the upper chamber 38 30 or the wellbore pressure outside the cylinder 26, A_{lc} is the cross-sectional area of the lower chamber 40.

The total force, F_{total} , that is applied to the piston portion 34 by the downhole tool 18

can be expressed as:

$$F_{\text{total}} = m_{\text{tool}}(g - a) + F_{\text{drag}} \quad (2)$$

where m_{tool} is the mass of the downhole tool 18, g is the acceleration due to gravity, a is the acceleration of the downhole tool 18, and F_{drag} is the drag force acting on the downhole tool

5 18. Drag force and acceleration are considered to be positive when acting in the same direction as gravity.

Assuming that the weight of the sensor section 24 and the weight of the connecting body 62 is negligibly small compared to the weight of the downhole tool 18, then the net force, F_{net} , resulting from the pressure differential across the piston portion 34 can be
10 equated to the total force, F_{total} , applied to the piston portion 34 by the downhole tool 18, and the pressure, P_{lc} , in the lower chamber 40 can then be expressed as:

$$P_{lc} = \frac{1}{A_{lc}} [m_{\text{tool}} \cdot (g - a) + F_{\text{drag}} + P_{uc} \cdot A_{lc}] \quad (3)$$

From the expression above, it is clear that the pressure, P_{lc} , in the lower chamber 40 changes as the downhole tool 18 is accelerated or decelerated. These pressure changes are
15 transmitted to the pressure transducer 54 through the fluid in the lower chamber 40 and the pressure path. The pressure transducer 54 responds to the pressure changes in the lower chamber 40 and converts them to electrical signals. For a given acceleration or deceleration, the size of a pressure change or pulse can be increased by reducing the cross-sectional area, A_{lc} , of the lower chamber 40.

20 In operation, the downhole assembly 10 is lowered into the wellbore 12 with the lower chamber 40 and pressure path filled with a pressure-transmitting medium. When the downhole assembly 10 is accelerated in the upward direction, the total force, F_{total} , which is applied to the piston portion 34 by the downhole tool 18 increases and results in a corresponding increase in the pressure, P_{lc} , in the lower chamber 40. When the downhole
25 tool 18 is accelerated in the downward direction, the force, F_{total} , which is applied to the piston portion 34 by the downhole tool 18 decreases and results in a corresponding decrease in the pressure, P_{lc} , in the lower chamber 40. The downhole assembly 10 may also be decelerated in either the upward or downward direction to effect similar pressure changes in the lower chamber 40. The pressure changes in the lower chamber 40 are detected by the
30 pressure transducer 54 as pressure pulses. Moving the downhole assembly 10 in prescribed patterns will produce pressure pulses which can be converted to electrical signals that can be

interpreted by the electronics cartridge 20 in the downhole tool 18 as command signals.

If the downhole assembly 10 becomes stuck and jars are used to try and free the assembly, the pressure differential across the piston portion 34 can become very high. If the bottom-hole pressure, i.e., the wellbore pressure at the exterior of the downhole assembly 10, 5 is close to the pressure rating of the downhole assembly 10, then the pressure transducer 54 can potentially be subjected to pressures that are well over its rated operating value. To prevent damage to the pressure transducer 54, the fill plug 100 may be provided with a rupture disc 108 which bursts when the pressure in the lower chamber 40 is above the pressure rating of the pressure transducer 54. When the rupture disc 108 bursts, fluid will 10 drain out of the lower chamber 40 and the pressure path, through the fill port 96, and out of the cylinder 26. As the fluid drains out of the lower chamber 40 and the pressure path, the piston portion 34 will move to the lower end of the cylinder 26 until it reaches the end of travel, at which time the hydraulic strain sensor 16 becomes solid and the highest pressure 15 the pressure transducer 54 will be subjected to is the bottom-hole pressure. Instead of using a rupture disc, a check valve or other pressure responsive member may also be arranged in the fill port 96 to allow fluid to drain out of the lower chamber 40 when necessary.

If the downhole assembly 10 becomes unstuck, commands can no longer be generated using acceleration or deceleration of the downhole assembly 10. However, 20 traditional methods such as manipulation of surface wellhead controls or movement of the downhole assembly 10 over fixed vertical distances in a column of liquid can still be used. When traditional methods are used, the pressure transducer 54, which is now in communication with the wellbore, will detect changes in wellbore or bottom-hole pressure around the hydraulic strain sensor 16 and transmit signals that are representative of the 25 pressure changes to the electronics cartridge 20. It should be noted that while the downhole assembly 10 is stuck, pressure signals can still be sent to the downhole tool 18 by alternately pulling and releasing on the conveyance device 14.

The invention is advantageous in that pressure signals can be generated by simply accelerating or decelerating the downhole tool. The pressure signals are generated at the 30 downhole tool and received by the downhole tool in real-time. The invention can be used with traditional methods of pressure-signal transmission, i.e., manipulation of surface wellhead controls or movement of the downhole tool over fixed vertical distances in a column of liquid.

While the invention has been described with respect to a limited number of embodiments, those skilled in the art will appreciate numerous variations therefrom without departing from the spirit and scope of the invention.

CLAIMS

What is claimed is:

- 1 1. A hydraulic strain sensor for use with a downhole tool, comprising:
 - 2 a housing having two chambers with a pressure differential between the two
 - 3 chambers;
 - 4 a mandrel disposed in the housing and adapted to be coupled to the tool such that the
 - 5 weight of the tool is supported by the pressure differential between the two
 - 6 chambers; and
 - 7 a pressure-responsive sensor in communication with one of the chambers, the
 - 8 pressure-responsive sensor being arranged to sense pressure changes in the
 - 9 one of the chambers as the tool is accelerated or decelerated and to generate
 - 10 signals representative of the pressure changes.
- 1 2. The hydraulic strain sensor of claim 1, wherein the pressure-responsive sensor
- 2 further senses pressure changes in the one of the chambers when there is a change in external
- 3 force applied to the tool.
- 1 3. A hydraulic strain sensor for use with a downhole tool, comprising:
 - 2 a housing having an end adapted to be coupled to a conveyance device so as to be
 - 3 lowered into a wellbore on the conveyance device, the housing having a first
 - 4 chamber and a second chamber defined therein, the first chamber being
 - 5 exposed to pressure outside the first housing through a port in the housing;
 - 6 a mandrel slidably disposed in the housing, the mandrel having a piston portion with
 - 7 one side exposed to pressure in the first chamber and another side exposed to
 - 8 pressure in the second chamber;
 - 9 means for generating pressure signals in response to pressure changes in the second
 - 10 chamber as the tool is accelerated or decelerated; and
 - 11 a fluid path filled with pressure-transmitting medium and arranged to transmit
 - 12 pressure changes in the second chamber to the means for generating pressure
 - 13 signals.

- 1 4. A hydraulic strain sensor for use with a downhole tool, comprising:
2 a first housing having an end adapted to be coupled to a conveyance device so as to
3 be lowered into a wellbore on the conveyance device, the first housing having
4 a first chamber and a second chamber defined therein, the first chamber being
5 exposed to pressure outside the first housing through a port in the housing;
6 a mandrel slidably disposed in the first housing, the mandrel having a piston portion
7 with one side exposed to pressure in the first chamber and another side
8 exposed to pressure in the second chamber;
9 a second housing coupled to the mandrel and having a pressure-responsive sensor
10 disposed therein, the second housing being adapted to be coupled to the tool
11 such that the weight of the tool is supported by pressure differential across the
12 piston portion; and
13 a fluid path extending from the second chamber to the pressure-responsive sensor,
14 the fluid path being filled with a pressure-transmitting medium and arranged
15 to transmit pressure changes from the second chamber to the pressure-
16 responsive sensor as the tool is accelerated or decelerated;
17 wherein the pressure-responsive sensor generates signals representative of the
18 pressure changes in the second chamber and transmits the signals to the tool.
- 1 5. The hydraulic strain sensor of claim 4, wherein the fluid path extends through the
2 mandrel and the piston portion includes a port for selective fluid communication
3 between the first chamber and the fluid path.
- 1 6. The hydraulic strain sensor of claim 5, wherein a plug is provided to prevent fluid
2 communication between the first chamber and the fluid path.
- 1 7. The hydraulic strain sensor of claim 6, wherein the plug includes a pressure-
2 responsive member which allows fluid communication between the first chamber and
3 the fluid path when the pressure in the first chamber reaches a predetermined value.
- 1 8. The hydraulic strain sensor of claim 7, wherein the predetermined value is the
2 maximum operating pressure of the pressure-responsive sensor.

- 1 9. The hydraulic strain sensor of claim 7, wherein a connecting body couples the
2 mandrel to the sensor housing and the fluid path extends through the connecting
3 body.
- 1 10. The hydraulic strain sensor of claim 9, wherein the connecting body includes a port
2 for selective fluid communication with the fluid path.
- 1 11. The hydraulic strain sensor of claim 10, wherein the sensor housing includes an
2 electrical connector which is adapted to be connected to the tool and through which
3 signals are transmitted from the pressure-responsive sensor to the tool.
- 1 12. An apparatus for use in a wellbore, comprising:
 - 2 a housing adapted to be lowered into the wellbore, the housing having a first
3 chamber and a second chamber, the first chamber being exposed to pressure
4 outside the housing through a port in the housing, the second chamber being
5 filled with a pressure-transmitting medium;
 - 6 a mandrel slidably disposed in the housing, the mandrel having a piston portion with
7 one side exposed to pressure in the first chamber and another side exposed to
8 pressure in the second chamber;
 - 9 a downhole tool coupled to the mandrel so as to be supported by the pressure
10 differential across the piston portion; and
 - 11 a pressure-responsive sensor in communication with the second chamber, the
12 pressure-responsive sensor being responsive to pressure changes in the
13 second chamber as the tool is accelerated or decelerated and generating
14 signals representative of the pressure changes;
 - 15 wherein the tool performs a downhole operation in response to the signals generated
16 by the pressure-responsive sensor.
- 1 13. The hydraulic strain sensor of claim 12, wherein the pressure-responsive sensor
2 further senses pressure changes in the second chamber when there is a change in external
3 force applied to the tool.

1 14. The hydraulic strain sensor of claim 13, wherein the change in external force applied
2 to the tool is generated by pulling on and releasing the tool.

1 15. A method of generating pressure signals for operating a downhole tool, comprising:
2 providing a hydraulic strain sensor having a housing with two chambers, a mandrel
3 disposed in the housing, and a pressure-responsive sensor in communication
4 with one of the chambers;
5 providing a pressure differential between the two chambers;
6 coupling the tool to the mandrel such that the weight of the tool is supported by the
7 pressure differential between the two chambers;
8 lowering the hydraulic strain sensor and the tool downhole on a conveyance device;
9 manipulating the conveyance device to accelerate or decelerate the tool;
10 detecting pressure changes in the one of the chambers using the pressure-responsive
11 sensor; and
12 transmitting signals representative of pressure changes in the one of the chambers to
13 the tool.

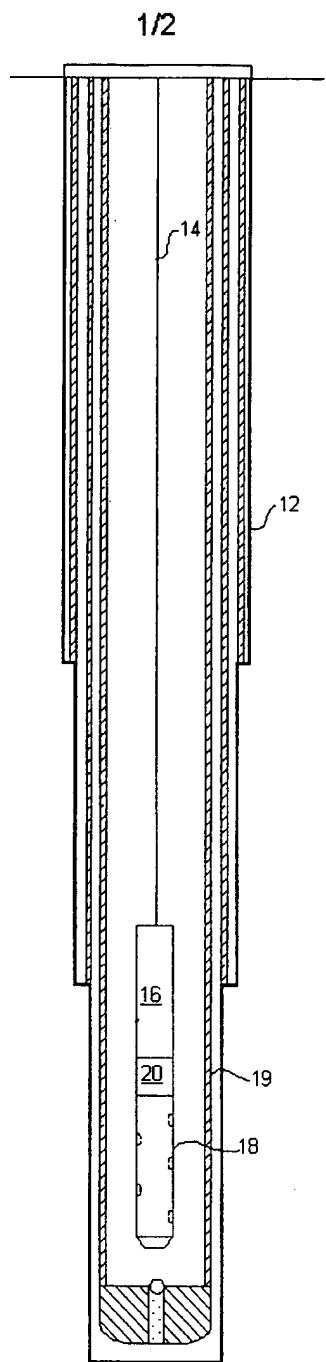


FIG. 1

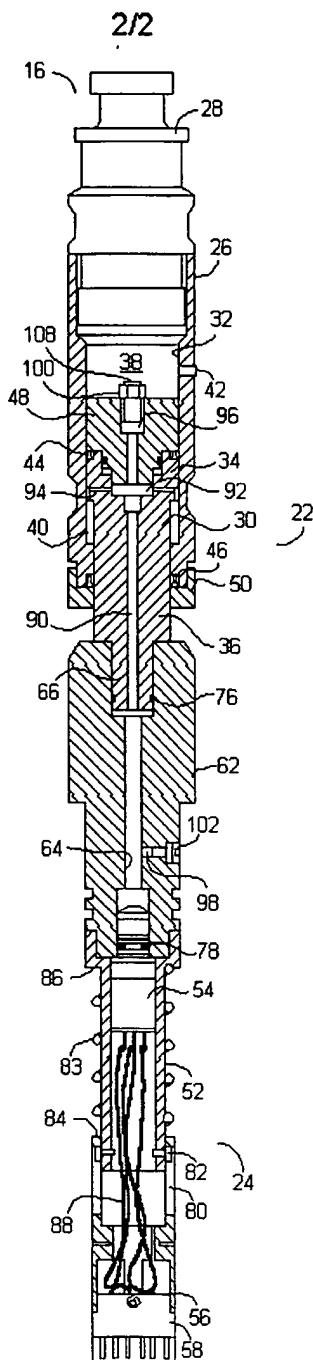
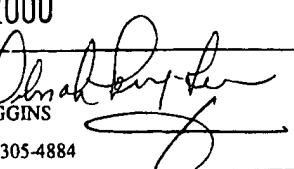


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/05542

A. CLASSIFICATION OF SUBJECT MATTER IPC(7) :E21B 49/00, 49/10 US CL :073/152.27, 152.22, 152.46; 166/250.07, 254.20 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) U.S. : 073/152.51, 152.22, 152.27, 152.55, 152.46, 152.31, 152.52, 152.18, 152.02, 784.00; 166/250.01, 250.07, 264, 254.20, 250.10		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched none		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) Please See Extra Sheet.		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,184,508 A (DESBRANDES) 09 February 1993 (09.02.93) see entire document.	1-2 and 15
T	US 5,900,545 A (SACKS et al.) 04 May 1999 (04.05.99) see entire document.	1-11 & 15
A	US 5,065,619 A (MYSKA) 19 November 1991 (19.11.91) see entire document.	1-2 and 15
A	US 4,860,580 A (DUROCHER) 29 August 1989 (29.08.89) see entire document.	1 - 15
A	US 5,329,811 A (SCHULTZ et al.) 19 July 1994 (19.07.94) see entire document.	1-5, 12-13 and 15
T	US 4,693,335 A (ALMON) 15 September 1987 (15.09.87) see entire document.	1-2, 12-13 and 15
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
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INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,099,700 A (MORIN et al.) 31 March 1992 (31.03.92) see entire document.	1-2 and 15
A	US 5,343,963 A (BOULDIN et al.) 06 September 1994 (06.09.94) see entire document.	1 - 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/05542

B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

STN/CAS search terms: housing, vessel, body, chassis or framework; two chambers, tanks or containers; downhole, wellbore or borehole; pressure differential; stress or strain; hydraulic or fluid; accelerate or decelerate; mandrel, adaptor, coupler or fixture; sensor, gauge or detector; fluid, formation or tool; pressure change or pressure variation